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(54) Title: OPEN-CHANNELED SPIRAL-WOUND MEMBRANE MODULE AND BRINE CONCENTRATION

(57) Abstract: There is disclosed a spiral-wound membrane module design for various membrane filtration techniques having significantly reduced fluid flow resistance in the feed stream path. Specifically, the inventive spiral-wound membrane module is designed having a corrugated entrance and exit spacers together over less than 10 % of the length of the spiral wound module and stiffener sheet wound to provide for uniform feed channel gap width. There is further disclosed a membrane-assisted evaporation process for removing water added to brine. Specifically, this process comprises using low-grade waste heat and air to evaporate water from diluted salt brine when water moves across a membrane in a liquid state.

OPEN-CHANNELED SPIRAL-WOUND MEMBRANE MODULE AND BRINE CONCENTRATION

Technical Field of the Invention

- 5 The present invention provides a spiral-wound membrane module design for various membrane filtration techniques having significantly reduced fluid flow resistance in the feed stream path. Specifically, the inventive spiral-wound membrane module is designed having a corrugated entrance and exit spacers together over less than 10% of the length of the spiral wound module and a stiffener sheet wound to provide for uniform feed channel gap width.
- 10 The present invention further provides a membrane-assisted evaporation process for removing water added to brine. Specifically, this process comprises using low-grade waste heat and air to evaporate water from diluted salt brine when water moves across a membrane in a liquid state.

Background of the Invention

- 15 In the field of pressure-driven membrane separations (*e.g.*, ultrafiltration, reverse osmosis, nanofiltration) there is frequently a problem of membrane fouling from contamination of other dissolved and suspended solids in feed streams. For feed streams that are not fouling, hollow fiber membrane module are most efficient and cost effective means of separation. However, hollow fiber membrane designs will foul most easily and cannot be used for the
- 20 majority of feed streams in industrial processing or waste treatment due to fouling problems.

- The next most expensive membrane design in terms of providing the greatest membrane surface area in a vessel per cost is a spiral wound configuration. In a spiral wound configuration, a permeate spacer, a feed spacer and two membranes are wrapped around a perforated tube and glued in place. The membranes are wound between the feed spacer and
- 25 the permeate spacer. Feed fluid is forced to flow longitudinally through the module through the feed spacer, and fluid passing through the membranes flows inward in a spiral through the permeate spacer to the center tube. To prevent feed fluid from entering the permeate spacer, the two membranes are glued to each other along their edges with the permeate spacer captured between them. The feed spacer remains unglued. A diagram of a cross-section of three wraps
- 30 of a standard module is shown in Figure 1. Module assemblies are wound up to a desired diameter and the outsides are sealed. In operation, multiple modules are placed in a tubular housing and fluid is pumped through them in series. The center tubes are plumbed together to allow removal of generated permeate.

- Spiral wound membrane designs have been used successfully but can also foul with
- 35 higher fouling feed streams. The fouling problem in standard spiral wound membranes is often due to the nature of the feed spacer that is required to be located through each of the feed channels. In addition, the presence of the feed spacer creates significant resistance to fluid flow. A typical feed spacer is a polymeric porous net-like material that the feed must be forced

through in the longitudinal direction (*i.e.*, the length) of the spiral wound membrane.

Therefore, spiral wound membrane designs can also have fouling problems in the feed spacer and membrane and incur significant fluid dynamic problems due to resistance of the feed spacer. However, spiral wound designs are less expensive than alternatives for only less-fouling feed streams.

For the most fouling feed streams (for examples, solutions containing high levels of suspended solids or tend to form gels upon concentration) a tubular design membrane module has been designed. A tubular design provides the least amount of membrane surface area per module length, and is most expensive to manufacture due to labor-intensive procedures for "potting" the tubular membranes within a module. Moreover, the inlet and outlet chambers associated with tubular designs are also most expensive. Therefore, there is a need in the art to replace the tubular design with a less expensive design and still be able to process highly fouling feed streams. The present invention was made to replace the tubular design with a spiral wound design for those feed streams that could not otherwise be processed (economically) in standard membrane modules having feed spacer designs.

Salt caverns have been used for storage of oil, particularly crude oil. When oil is to be pumped out of a salt cavern, a brine solution is pumped in to replace the oil. The brine concentrations are preferably within a range of 14-22.5% (by weight) of salt (mostly NaCl). However, this brine solution is generally stored in ponds and the ponds generally can take in rainwater that results are a net dilution of the brine with pure water. The effect of the diluted brine is a slow destruction of the salt cavern through removal of salt from the walls and eventual collapse of the cavern. Therefore, there is a need in the art to remove water from brine holding ponds and concentrate the brine to near saturation.

Salt caverns in Ontario, Canada and in Texas have ponds that take in an about 150,000 barrels (38 gallons to the barrel or about 140 liters to the barrel) or rainwater per year on average. The refinery is forced to either develop a process to remove water from brine ponds or build indoor tanks to hold brine. Similar brine concentration issues are present in the chloralkali industry for treating cooling tower blowdown wastewater.

Previous attempts at brine regeneration have attempted to use ultrafiltration membranes, specifically hydrophobic membranes such as polysulfone membranes in a pervaporation process or a membrane distillation process. Such processes use a hydrophobic membrane and heat to drive water into a vapor phase from the heated brine side to a permeate side. Water is vaporized in the heated brine and migrates across the membrane still in the gas phase to the permeate side. A vacuum often drives this. The membrane rejects salt and crystals often form on the brine side and foul the membrane. In another approach (U.S. Patent 4,316,774) the air is heated on the permeate side but this is wasted because air (unlike a liquid) cannot hold much heat. Moreover, significant problems with membrane fouling have been

encountered. Moreover, membrane wetting and fouling prevented vapor from permeating in to the membrane, effectively shutting down the process.

Therefore, there is a need to develop concentration techniques using membranes that can further concentrate brine to near saturation without local crystallization on the membrane and without utilization of significant amounts of energy in an evaporation or pervaporation process. The needed membrane should also be able to resist hydrolysis caused by high heat, high pH and cleaning solutions as it will operate in harsh and caustic environments.

Summary of the Invention

The present invention provides a spiral wound membrane module having a length and a radius and a circular cross section, having reduced fluid flow resistance, comprising:

(a) an envelope sandwich having a width equal to the length of the membrane module and comprising a layer of membrane next to a layer of permeate spacer material next to a stiffener means, next to a layer of permeate spacer material next to a layer of membrane, and wherein the envelope sandwich is wrapped increasing the radius of the membrane module; and

(b) a structural assembly located between each wrap of the envelope sandwich to provide an open path for each feed chamber throughout the length of the membrane module.

Preferably, the stiffener means is composed of a hard shell sheet or an extruded or calendered rib. Most preferably, a rib stiffener means run in the same direction as permeate flow and provide permeate channels. Preferably, the structural assembly extends no more than 10% of the length of the membrane module. Preferably, the structural assembly is located at both ends of the membrane module. Preferably, the membrane module further comprises a perforated or porous tube extended throughout the length of the membrane module and located axially around a cylinder axis of the membrane module. Most preferably, the perforated or porous tube is used to collect permeate.

Preferably, the stiffener in the form of a sheet is made from a rigid sheet having a thickness of from about 0.1 mm to about 3 mm, most preferably from about 0.5 mm to about 1 mm. Preferably, the stiffener in the form of a sheet is made from a rigid material selected from the group consisting of PVC (polyvinyl chloride), C-PVC (chlorinated polyvinyl chloride) polypropylene, polyethylene, acrylic, stainless steel, copper, tin, and aluminum. Most preferably, the stiffener sheet is polyethylene for food uses or PVC for non-food uses, or C-PVC for high temperature uses. Preferably, the structural assembly is a corrugated pattern ribbon. Preferably, the structural assembly is a rigid material, wherein the rigid material is selected from the group consisting of polyethylene, stainless steel, aluminum, acrylic, and polycarbonate.

The present invention further provides a process for making a spiral wound membrane module having a length and a radius and a circular cross section, having reduced fluid flow resistance, comprising

(a) assembling an envelope sandwich having a width equal to the length of the membrane module and comprising a layer of membrane next to a layer of permeate spacer material next to a layer of stiffener means next to a layer of permeate spacer material next to a layer of membrane, and wherein the envelope sandwich is wrapped increasing the radius of the membrane module;

(b) assembling a structural assembly on either end of the envelope sandwich; and
(c) wrapping the envelope sandwich having the structural assembly and glue to form the spiral wound membrane module.

Preferably, the stiffener means is composed of a hard shell sheet or an extruded or calendered rib. Most preferably, a rib stiffener means run in the same direction as permeate flow and provide permeate channels. Preferably, the process further comprises before step (c) adding glue to either end of the envelope sandwich. Preferably, the structural assembly extends no more than 10% of the length of the membrane module. Preferably, the membrane module further comprises a perforated or porous tube extending throughout the length of the membrane module and located axially around a cylinder axis of the membrane module and upon which the sandwich assembly is wrapped.

Preferably, the stiffener in the form of a sheet is made from a rigid sheet having a thickness of from about 0.1 mm to about 3 mm, most preferably from about 0.5 mm to about 1 mm. Preferably, the stiffener in the form of a sheet is made from a rigid material selected from the group consisting of PVC (polyvinyl chloride), C-PVC (chlorinated polyvinyl chloride) polypropylene, polyethylene, acrylic, stainless steel, copper, tin, and aluminum. Most preferably, the stiffener sheet is polyethylene for food uses or PVC for non-food uses, or C-PVC for high temperature uses. Preferably, the structural assembly is a corrugated pattern ribbon. Preferably, the structural assembly is a rigid material, wherein the rigid material is selected from the group consisting of polyethylene, stainless steel, aluminum, acrylic, and polycarbonate.

The present invention provides a process for concentrating diluted feed or brine or other aqueous solution for concentration, comprising:

(a) providing a hydrophilic membrane having a rejection property of 500 kDa cutoff or lower, having a first side designed to be in contact with diluted feed, and having a second side designed to be in contact with air, wherein the hydrophilic membrane is not able to reject salt;

(b) pumping the diluted feed at a temperature of from about 10 °C to about 100 °C across the first side of the hydrophilic membrane while blowing an air stream or other gas across the second side of the hydrophilic membrane; and

(c) removing water from the diluted feed by evaporating the water into the air stream blown across the second side of the hydrophilic membrane.

Preferably, the hydrophilic membrane is an asymmetric hydrophilic membrane further comprising a fabric layer on the second side of the membrane to provide mechanical strength to the membrane. Most preferably, the fabric is a polyester net, having about 60% open area and about 0.07 mm thick. Preferably, the fabric is a silkscreen material. Preferably, the hydrophilic membrane is made from a cellulose material or polyvinyl alcohol. Most preferably, the cellulose material is selected from the group consisting of cellulose acetate, cellulose diacetate, cellulose triacetate, cellulose acetate butyrate, cellulose propionate, and combinations thereof.

Preferably, the diluted feed is heated using any available heat source to a temperature of from about 10 °C to about 95 °C. Most preferably, the diluted feed is heated to a temperature of from about 50° C to about 95 °C. Preferably, the air stream on the second side of the membrane is blown at a velocity of from about 5 cm/sec to about 100 m/sec. Most preferably, the velocity of the air across the membrane is about 100 cm/sec.

The present invention further provides a device for osmotic membrane evaporation of brine and other aqueous media (feed), comprising:

(a) a hydrophilic membrane having a first side and a second side, having a rejection property of 500 kDa cutoff or lower, wherein the hydrophilic membrane is not able to reject salt;

(b) an enclosed air flow chamber having an air flow blowing means adjacent to an inlet and an outlet defined by the second side of the hydrophilic membrane; and

(c) a heating means for the feed located adjacent to the inflow of the brine flow chamber.

Preferably, the hydrophilic membrane is an asymmetric hydrophilic membrane further comprising a fabric layer on the second side of the membrane to provide mechanical strength to the membrane. Most preferably, the fabric is a polyester net, having about 60% open area and about 0.07 mm thick. Preferably, the fabric is a silkscreen material. Preferably, the hydrophilic membrane is made from a cellulose material or polyvinyl alcohol. Most preferably, the cellulose material is selected from the group consisting of cellulose acetate, cellulose diacetate, cellulose triacetate, cellulose acetate butyrate, cellulose propionate, and combinations thereof.

Brief Description of the Drawings

Figure 1 shows a prior art cut away in an axial direction showing product flow direction (through the length of a module) through a feed chamber having feed spacer (cross hatched) material contained within the entire area of the feed chamber. In addition, there is permeate spacer located throughout the permeate chamber. In addition, the membrane is shown along with glue on the outer edges to maintain the integrity of the permeate chamber.

Figure 2 shows a cut away in the axial direction of the inventive spiral-wound membrane module design showing the novel open feed channels having a stiffener sheet

between membrane layers. There is also a glued plug at either end, similar to the prior art design to form the permeate chamber. In addition there is a corrugated feed chamber spreader at either end to provide for a uniform feed chamber gap maintainer.

5 Figure 3 shows an outside view of the inventive spiral wound membrane module showing standard flow characteristics of feed and permeate. The end view shows the corrugated feed chamber spreader at the end.

Figure 4 shows an end view close up again illustrating the corrugated feed chamber spreader and each layer having a membrane, permeate spacer, glue, permeate spacer and membrane.

10 Figure 5 shows an embodiment of the inventive spiral wound membrane module having ribs as the stiffener means.

Figure 6 provides a schematic of the inventive membrane evaporation process, wherein water in a liquid state (with salt) from a diluted brine solution crosses a membrane from the first side to the second side through absorbtivity and is evaporated into an air stream located on
15 the second side of the membrane.

Figure 7 shows an overall schematic showing the membrane structure of Figure 6 on the left side and where a blower and a heat exchanger to capture and reuse excess heat generate airflow.

20 Figure 8 shows a graph of flux rates for brine solutions at increasing concentrations, as provided in Example 1.

Detailed Description of the Invention

The present invention provides an improved membrane design for spiral wound membranes that provide the cost advantages and space savings of spiral wound with superior flux and fouling characteristics. The advantage of a spiral wound membrane design prior to
25 the present invention is that it is inexpensive and has high membrane density ($\sim 30\text{m}^2$ per 20 cm diameter by 100 cm long element). Its drawback is that it is highly susceptible to fouling since the feed must flow longitudinally through a net-like feed spacer. The fibers of the feed spacer allow suspended solids to become lodged and blind the membrane, degrading performance and inhibiting cleaning. Pressure drops are also high in the flow through the feed spacer, which
30 makes it impossible to achieve the fluid velocities that have been shown to provide the best performance of membranes.

Another membrane module design in common usage is the "tubular" design. In this design, the fluid is pumped at high velocity down the center of a tubular membrane (5mm to 30
35 mm in diameter), and an exterior housing contains the fluid permeating the membrane. Often multiple tubes are bundled in a single housing. This design has the advantage that the flow path is unobstructed, allowing very high-solids fluids to be filtered. The disadvantage of this design is its high cost and low membrane density. Thus, there is a need to combine the

expense and density advantages of spiral wound with flow path advantages of tubular. The present invention has achieved this.

Module Design

The invention is a spiral module design that does not require a feed spacer, thus providing the advantages of unobstructed feed channels, at far lower cost than tubular modules. Instead, the inventive membrane is a spiral wound design but without traditional spacer materials. Specifically, the present invention provides a spiral wound membrane module having a length and a radius and a circular cross section, having reduced fluid flow resistance, comprising

(a) an envelope sandwich having a width equal to the length of the membrane module and comprising a layer of membrane next to a layer of permeate spacer material next to a layer of stiffener sheet next to a layer of permeate spacer material next to a layer of membrane, and wherein the envelope sandwich is wrapped increasing the radius of the membrane module; and

(b) a structural assembly located between each wrap of the envelope sandwich to provide an open path for each feed chamber throughout the length of the membrane module.

Essentially, the inventive membrane provides a "layered" approach to a spiral wound design with a stiff backing material and no spacer material through most of the flow path. The layered membrane sandwich is shown in a cut-away view of three channels in Figure 2 wherein the sandwich layer for the middle section of the spiral wound module forms a membrane (green) on a permeate spacer material (red), on a polymeric stiffener material (dark blue), permeate spacer material (red), and another membrane (green). Thus, the membrane is always between the permeate channel kept open by conventional spacer technology and a larger feed channel kept open by the polymeric stiffener (though the larger middle section of the module) and without conventional spacer technology. Thus, the vast majority of the feed channel is open to significantly improve the flow rates and pressure drips, especially for high-suspended solids feed streams (e.g., landfill leachate).

Further with reference to Figure 2, either end of the module has a feed channel spacer to align the polymeric stiffener sandwich to have open feed channels, preferably a corrugated plastic material as shown in Figure 2 and as a "corrugated spacer" in Figure 4, and glue (Figure 2, light blue) to anchor the polymeric stiffener sandwich component and provide for permeate to be channeled to the center of the spiral wound module.

Therefore, the inventive spiral wound module is designed in a similar fashion to a typical spiral wound membrane module except that there is no feed chamber spacer at all through most of the middle segment of the module (i.e., 90%+ of the length) and the feed chamber remains patent with superior flow characteristics and pressure drops. This inventive design is illustrated in Figures 2-5. The design is similar to a standard spiral wound design, except it requires no feed spacer. In a standard spiral wound module the feed spacer material

fills the entire feed channel. In the inventive design, by contrast, a thick, corrugated spacer is used only at the front and back edge of the feed channel. Fluid pressure then keeps the membranes in contact with the permeate spacer and keeps the feed channels unobstructed. A uniform feed channel width is ensured by employing a plastic stiffener in the permeate channel. The stiffener is typically 0.5 mm to 1 mm thick and made from PVC, polypropylene, or polyethylene. To provide for permeate flow on both sides of the stiffener, two permeate spacers are used with the stiffener between them. As in the standard spiral wound design, the membranes are glued along the edges, capturing the permeate spacers and stiffener.

Ultrafiltration modules with the inventive design have been made and tested for performance criteria. Specifically, 24cm diameter by 60 cm long element with a feed channel gap width of 3 mm had a pressure drop of 1 kPa when feed fluid velocities inside the module were 0.5 m/sec. The module contained an effective membrane area of 10 m². To put these data into perspective, the pressure drop experienced is about ten-fold lower than a conventional spiral wound device of about the same area and size having a conventional feed chamber spacer.

The inventive membrane module design can be applied to a variety of applications ranging from microfiltration through ultrafiltration to reverse osmosis. Initial tests of the fouling resistance of the membrane have been conducted by ultrafiltration of a heavily soiled, machine shop cutting fluid containing emulsified oil. At 75% water removal, 0.5 m/sec cross-flow velocity, and 300 kpa pressure, the membrane flux declined less than 20% in 100 hours of operation without any cleanings. A similar membrane in a traditional spiral wound membrane module would foul and a much higher rate.

Osmotic Membrane Evaporation Process and Device

The inventive membrane evaporation process is an improvement over pervaporation and membrane distillation because the inventive process and device uses a hydrophilic membrane as opposed to a hydrophobic membrane required to be used in a pervaporation device. Another difference is that water vapor is driven across the membrane in pervaporation driven by pressure gradients of water vapor through the pores in the membrane by a vacuum. Thus, a vapor pressure gradient drives the separation of water from salt as water is vaporized on the feed side of the hydrophobic membrane and drawn to the colder side a vapor. Low vapor pressures and microscopic pore diameters cause the flux in pervaporation to be slow.

The present process, by contrast, allows for water in a liquid state (and salt) transport across a hydrophilic membrane, such that the water evaporates directly into the air stream. Since the brine feed is heated, the cooler air that gets heated by contact with the membrane, allowing the air to hold more water, picks up water. High air flows improve the water evaporation rate because heat transfer through the membrane drives evaporation, and the most heat transfer occurs when the largest temperature differential occurs between the brine and the air. There is no vacuum pump as the air is blown across the second side of the hydrophilic

membrane. In the inventive process, near saturation, salt crystals will form on the second side of the hydrophilic membrane, indicating that the hydrophilic membrane is not rejecting salt. The crystals form when the water evaporates into the air flow on the second side of the hydrophilic membrane. The salt crystal formation is reversed when the air flow is temporarily
5 turned off and the salt redissolves and diffuses back into the brine.

The inventive process and device uses a hydrophilic membrane. The hydrophilic membrane thickness without a support layer is in the range of from about 10 to about 300 μm , in particular from about 20 to about 120 μm and ideally about 0.1 mm thick. In a preferred embodiment, the hydrophilic membrane is a cellulose-based membrane with ultrafiltration or
10 tighter rejection properties. Using a hydrophilic membrane (as opposed to a hydrophobic membrane) allows for water to transfer across the membrane as a liquid and evaporate from the back or second side of the membrane into an air stream. The evaporation process is augmented by heat transferred through from the feed solution being evaporated. Thus, the limiting resistance is heat transferred through the hydrophilic membrane. For this reason, a heat
15 conductive membrane material, such as cellulose, even cellulose triacetate, is preferred. In fact, the more heat that can be transferred across the hydrophilic membrane, couples with faster air flows across the second side of the hydrophilic membrane, will allow for faster evaporation and accelerating the process for brine concentration. Moreover, hydrophobic membranes, such as those used in pervaporation processes, are too thermally insulating to be useful for the
20 inventive process. Moreover, it is important to keep air flow on the second side of the hydrophilic membrane as high as possible.

A hydrophilic membrane is further important because in many brine solutions there are trace amounts of substances that will quickly foul hydrophobic membranes, requiring them to be cleaned frequently. In contrast, hydrophilic membrane will operate with infrequent
25 cleanings in solutions containing a variety of foulants, such as fats, oils, proteins, paraffins and other organics. In any salt evaporation process as the solution approaches saturation, salt crystal formation can hinder evaporation and cause frequent shut downs and cleanings. This is why cooling towers cannot make saturated brine solutions as they will rapidly cake up and collapse. Evaporators, even those made with expensive non-corrosive components, also cake
30 up. However, according to the inventive process, salt crystals can form on the second side of the hydrophilic membrane, but turning off the air flow can reverse this crystallization. Moreover, the salt crystals on the second side of the hydrophilic membrane are hygroscopic and will help to pull water through the membrane.

The benefits of this invention are illustrated in the following example.

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Example 1

This example illustrates the results of a study to reduce brine volume at a salt cavern associated with a refinery. The salt caverns at refinery "X" annually take on about 150,000 barrels of rain water per year. Refinery X needs a process to remove rain water from the brine.

The brine concentration ranges from 14 to 22.5% NaCl by weight. A bench scale test was run and used to estimate the costs of rain water removal from the brine in terms of both capital costs and operating costs (electricity and membrane replacement). In a bench scale set up (Figure 7), showing the brine (feed) recirculated first through a heat exchanger, then passing an osmotic membrane evaporation module, and finally back to the tank. The amount of water evaporated was calculated by recording tank level changes with time. Ambient (room) air was used and blown by a bench-scale regenerative blower on the second side of the hydrophilic membrane. Energy was provided by a set-point controlled electrical resistance heater that heated a recirculating loop. The heated water loop transferred its heat energy to the circulating brine in a heat exchanger.

Three types of membranes were tested, one formulated for high flux, one formulated for long life and one formulated for both high flux and long life. All three membranes were cast onto high flux cloth backing. Different brine temperatures (43, 60 and 77 °C) were tested by adjusting the water loop temperature. The airflow rate was set to full flow of about 0.66 m³/min at STP or half flow of 0.33 m³/min. In addition to brine levels in the tank, the collected volume of condensate, degrees brix of the brine sample (20 degrees brix is equivalent to 17.5% by weight of NaCl), degrees brix of the collected condensate, brine temperatures and pressures in and out of the membrane module, brine flow rates, air flow rates and air temperatures were also evaluated. The flux of the overall process was calculated by dividing the change in tank levels in liters by the time in hours between readings (often 30 min) and the dividing by the membrane area (0.33 m²). This calculated flux was represented by LMH or liters of water transferred per square meter of membrane each hour. Alternatively, GFD was calculated as gallons of water transferred per square foot of membrane each 24 hour day with the conversion being 1.000 LMH = 0.589 GFD. The flux rate was checked by the energy balance about the module. Thus, the energy to evaporate the water (water evaporation rate times latent heat of vaporization) was approximately equal to the energy lost from the brine (brine flow rate times specific heat times temperature drop from the inlet to the outlet).

The flux from multiple runs with varying temperatures and membranes is shown in Figure 8. The values in Figure 8 are the averages of the fluxes at each of the conditions described on the abscissa. In general, the flux increased as the temperature increased and the flux decreased as the air flow decreased. The scatter of the data at 77 °C was most likely due to brine nearing or exceeding its saturation point (26 wt % at 20 °C). As the brine approached saturation, salt would begin to crystallize on the second side of the hydrophilic membrane. The crystallized salt increased mass-transfer resistance for the water to reach the evaporation interface and it increased the heat transfer resistance through the membrane, which kept the evaporation surface from cooling too much. However, the crystallized salt re-dissolved within minutes after turning off the fan.

These data (Figure 8) provide appropriate process parameters and sizing of an industrial sized device and process for brine concentration to be built and implemented.

We claim:

1. A spiral wound membrane module having a length and a radius and a circular cross section, having reduced fluid flow resistance, comprising:
 - (a) an envelope sandwich having a width equal to the length of the membrane module and comprising a layer of membrane next to a layer of permeate spacer material next to a layer of stiffener sheet next to a layer of permeate spacer material next to a layer of membrane, and wherein the envelope sandwich is wrapped increasing the radius of the membrane module; and
 - (b) a structural assembly located between each wrap of the envelope sandwich to provide an open path for each feed chamber throughout the length of the membrane module.
2. A process for making a spiral wound membrane module having a length and a radius and a circular cross section, having reduced fluid flow resistance, comprising
 - (a) assembling an envelope sandwich having a width equal to the length of the membrane module and comprising a layer of membrane next to a layer of permeate spacer material next to a layer of stiffener sheet next to a layer of permeate spacer material next to a layer of membrane, and wherein the envelope sandwich is wrapped increasing the radius of the membrane module;
 - (b) assembling a structural assembly on either end of the envelope sandwich; and
 - (c) wrapping the envelope sandwich having the structural assembly and glue to form the spiral wound membrane module.
3. The spiral wound membrane module of claim 1 or the process of claim 2, wherein the stiffener means is composed of a hard shell sheet or an extruded or calendered rib.
4. The spiral wound membrane module or the process of claim 3, wherein the rib stiffener means runs in the same direction as permeate flow and provide permeate channels.
5. The spiral wound membrane module of claim 1 or the process of claim 2, wherein the structural assembly extends no more than 10% of the length of the membrane module.
6. The spiral wound membrane module of claim 1 or the process of claim 2, wherein the structural assembly is located at both ends of the membrane module.
7. The spiral wound membrane module of claim 1 or the process of claim 2, wherein the membrane module further comprises a perforated or porous tube extended throughout the length of the membrane module and located axially around a cylinder axis of the membrane module.
8. The spiral wound membrane module or the process of claim 7, wherein the perforated or porous tube is used to collect permeate.
9. The spiral wound membrane module or the process of claim 3, wherein the stiffener sheet is made from a rigid sheet having a thickness of from about 0.1 mm to about 3 mm.

10. The spiral wound membrane module or the process of claim 9, wherein the stiffener sheet is made from a rigid sheet having a thickness of from about 0.5 mm to about 1 mm.

11. The spiral wound membrane module or the process of claim 3, wherein the stiffener sheet is made from a rigid material selected from the group consisting of PVC (polyvinyl chloride), C-PVC (chlorinated polyvinyl chloride) polypropylene, polyethylene, acrylic, stainless steel, copper, tin, and aluminum.

12. The spiral wound membrane module or the process of claim 11, wherein the stiffener sheet is polyethylene for food uses or PVC for non-food uses, or C-PVC for high temperature uses.

13. The spiral wound membrane module of claim 1 or the process of claim 2, wherein the structural assembly is a corrugated pattern ribbon.

14. The spiral wound membrane module of claim 1 or the process of claim 2, wherein the structural assembly is a rigid material, wherein the rigid material is selected from the group consisting of polyethylene, stainless steel, aluminum, acrylic, and polycarbonate.

15. A process for concentrating diluted feed or brine or other aqueous solution for concentration, comprising:

(a) providing a hydrophilic membrane having a rejection property of 500 kDa cutoff or lower, having a first side designed to be in contact with diluted feed, and having a second side designed to be in contact with air, wherein the hydrophilic membrane is not able to reject salt;

(b) pumping the diluted feed at a temperature of from about 10 °C to about 100 °C across the first side of the hydrophilic membrane while blowing an air stream or other gas across the second side of the hydrophilic membrane; and

(c) removing water from the diluted feed by evaporating the water into the air stream blown across the second side of the hydrophilic membrane.

16. A device for osmotic membrane evaporation of brine and other aqueous media (feed), comprising:

(a) a hydrophilic membrane having a first side and a second side, having a rejection property of 500 kDa cutoff or lower, wherein the hydrophilic membrane is not able to reject salt;

(b) an enclosed air flow chamber having an air flow blowing means adjacent to an inlet and an outlet defined by the second side of the hydrophilic membrane; and

(c) a heating means for the feed located adjacent to the inflow of the brine flow chamber.

17. The process of claim 15 or the device of claim 16, wherein the hydrophilic membrane is an asymmetric hydrophilic membrane further comprising a fabric layer on the second side of the membrane to provide mechanical strength to the membrane.

18. The process or the device of claim 17, wherein the fabric is a polyester net, having about 60% open area and about 0,07 mm thick.

19. The process or the device of claim 17, wherein the fabric is a silkscreen material.

5 20. The process of claim 15 or the device of claim 16, wherein the hydrophilic membrane is made from a cellulose material or polyvinyl alcohol.

21. The process or the device of claim 20, wherein the cellulose material is selected from the group consisting of cellulose acetate, cellulose diacetate, cellulose triacetate, cellulose acetate butyrate, cellulose propionate, and combinations thereof.

10 22. The process of claim 15 wherein the diluted feed is heated using any available heat source to a temperature of from about 10 °C to about 95 °C.

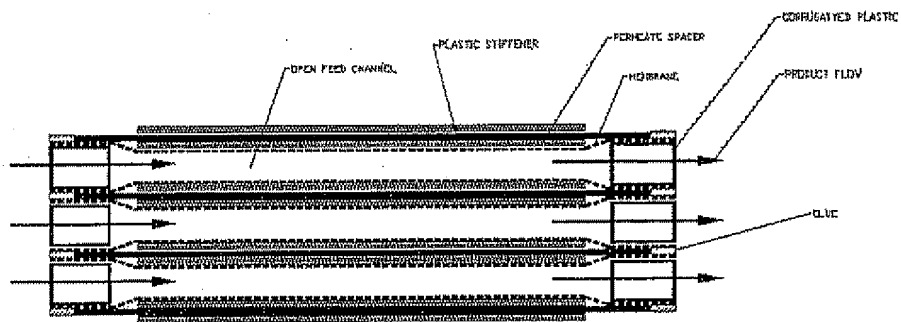
23. The process of claim 22 wherein the diluted feed is heated to a temperature of from about 50° C to about 95 °C.

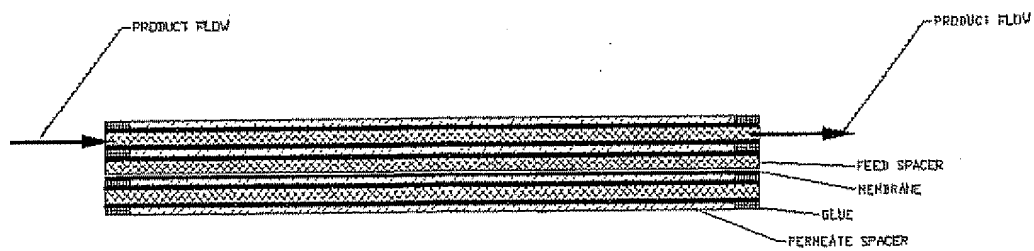
15 24. The process of claim 15 wherein the air stream on the second side of the membrane is blown at a velocity of from about 5 cm/sec to about 100 m/sec.

25. The process of claim 24 wherein the velocity of the air across the membrane is about 100 cm/sec.

Figure 1

CUT-AWAY VIEW OF THREE CHANNELS





CUT-AWAY VIEW OF THREE CHANNELS
OF A STANDARD SPIRAL WOUND MODULE

Figure 2

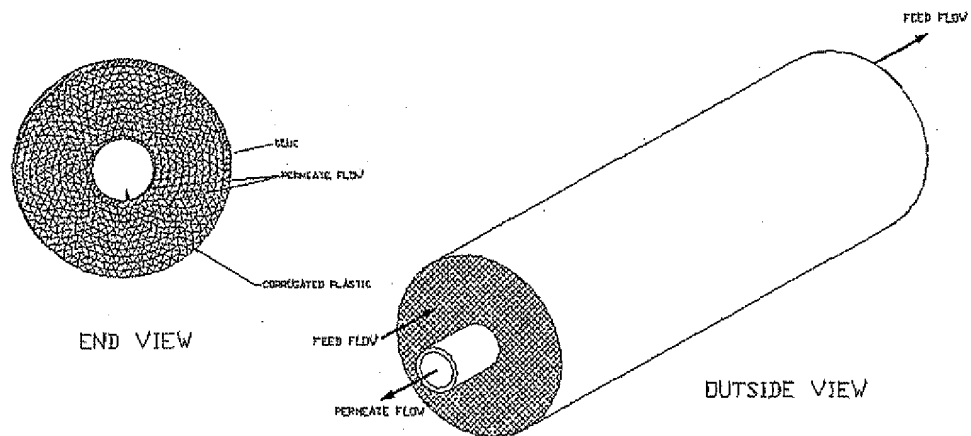
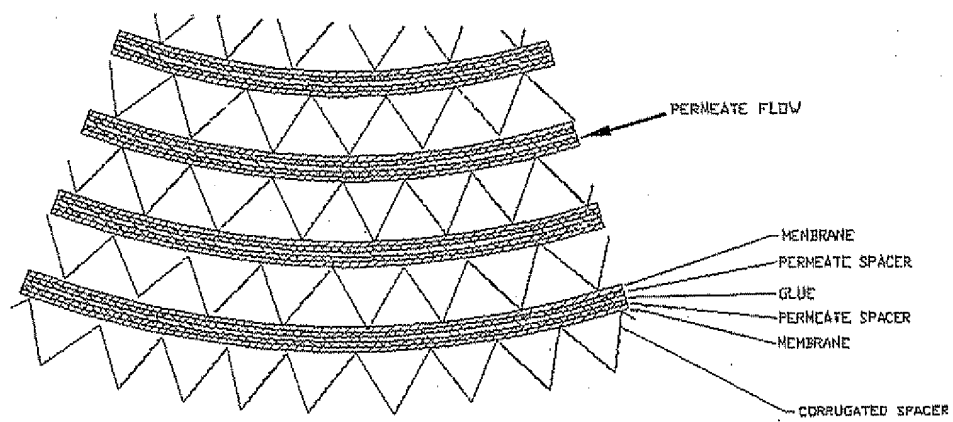


Figure 3



ENDVIEW CLOSE-UP

Figure 4

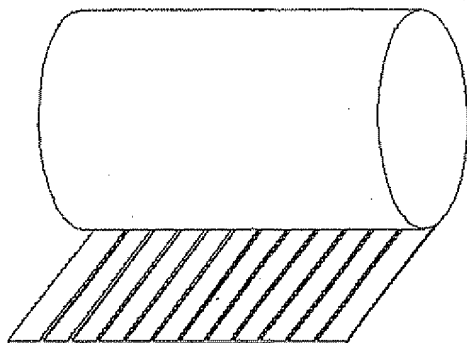


Figure 5

Figure 6

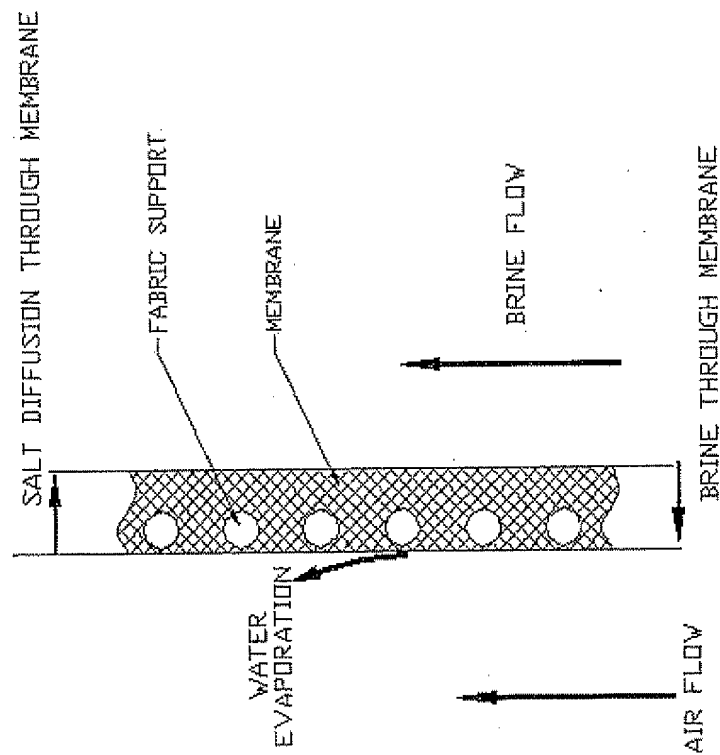
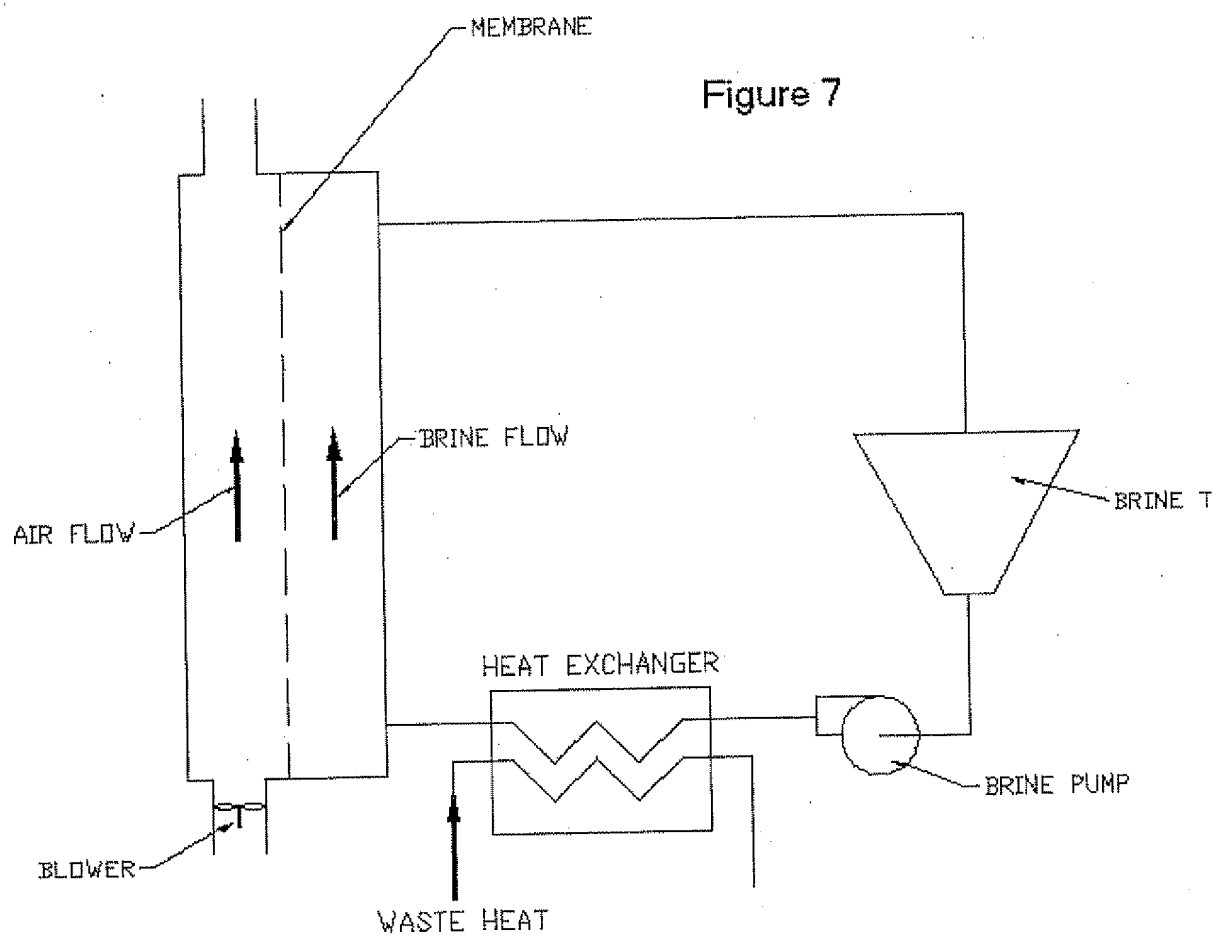
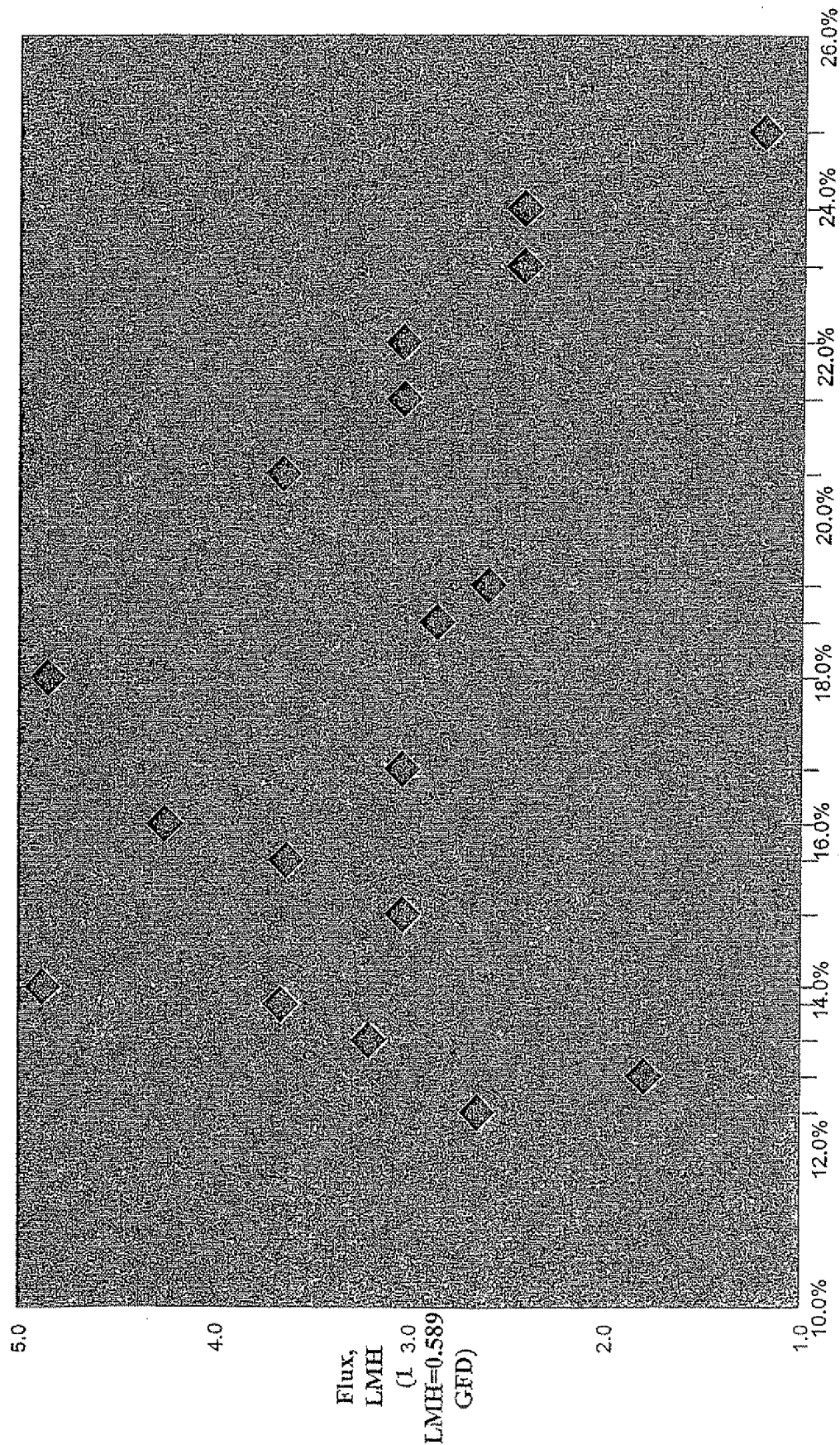


Figure 7



@ 110°F and 25 scfm
(43°C and 0.66 m³/min STP)



Brine wt %

Figure 8